

A Multi-Scale CA Approach for Modeling Regional-Local Urban Change

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1. Cellular automata for simulating urban growth in small urban settings

One of the goals of the study presented is develop a CA model applied to small urban areas and to assess its performance. The other goal of the study is related with testing the use of irregular cells on a CA approach. The cell structure is based on the use of irregular cells. The aim is to use cells designed from real-world irregular census tracts. The model works with a set of six aggregate cell states (or land use classes): (1) urban low density (ULD), (2) urban high density (UHD), (3) industry (IND), (4) non-urbanized urban areas (N-Urb), (5) non-urbanized industrial areas (N-UInd), and (6) areas where construction is highly restricted (Rest). Besides cell state, a set of other cell parameters are defined: cell accessibility, cell suitability, and neighborhood effect. Transition rules are applied through the consideration of a transition potential. The potential function is a calibrated value of accessibility, land use suitability, and neighborhood effect. Land use demand is proportional to the increase of population, as well as to the variation of construction density. The assessment of the model performance was made using contingency matrices and related *kappa* index. The consideration of the entire set of cell state for the calculation of the *kappa* index value would produce a distortion on its significance. To avoid this distortion, a modification of the *kappa* index measure was considered, accounting only the cell states that take part in the urban change dynamics. The calibration of the model was made through an optimization procedure called Particle Swarm with the goal of producing an intensive search of the set of calibration parameters that optimize the fitness function chosen for the model.

A set of 20 theoretical problems were created with the aim of simulate small municipalities not only in size but also in the total number of cells. These prototypes of spatial structures, depicted in Figure 1.1, were generated following the natural evolution of a territory, considering accessibility and a given probability of location regarding the distance to the centre of the settlements.

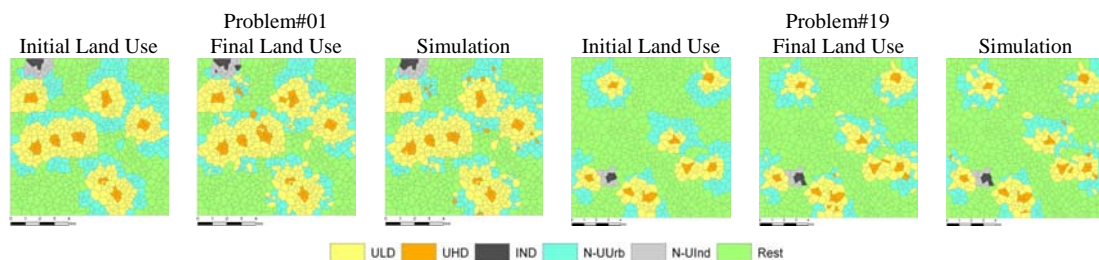
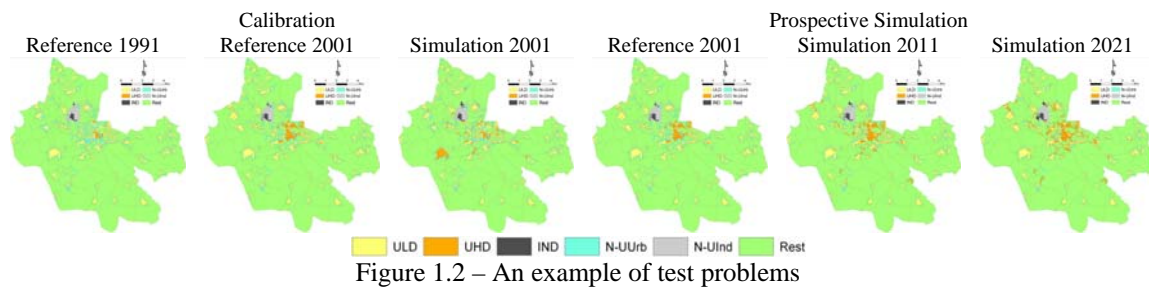


Figure 1.1 – An example of test problems

The model was also applied to a real-world case study – Condeixa-a-Nova, Portugal, (see Figure 1.2) – chosen among a set of small Portuguese municipalities that presented high population and built area growth rates for the past decades.

The results presented show promising possibilities of using CA for modeling urban change in small urban areas. The use of irregular cells also proved to be feasible. The assessment of the components of the transition potential must be improved in order to better simulate these phenomena. A multi-modal accessibility model will be developed to correctly assess local measures of accessibility. Land suitability will also be subjected

to further research in order to establish suitable measures of physical land characteristics. The concept of neighborhood should be more oriented for real urban structures rather than to its mathematical concept. The assessment of neighborhood relationships is another field that needs careful research. The use of local scale CA model is believed to produce good simulation results for urban change phenomena. The expertise on CA acquired in this study will be the basis of the development of a more ambitious integrated land use model, aimed to simulate urban change phenomena with a multi-scale approach. The main goal is to develop an innovative technology that could be applied to multi-scale urban studies.



2. New methodologies for simulating urban change phenomena with a multi-scale approach – conceptual issues

This section of this text is devoted to presenting the conceptual framework for a multi-scale modeling approach to urban growth phenomena based on CA. These issues are the starting point of the PhD research that is currently taking place at the Technical University of Catalonia.

The first issue considered was the multiple scale of approach. Different urban phenomena can be observed and modeled considering, on the one hand, cities as parts of larger regional systems and, on the other hand, cities themselves, where the driven forces of urban change depend on local variables. Therefore, the use of both regional and local scales is considered useful to correctly simulate a wide set of complex urban phenomena that occur on different spatial scales (or layers). The consideration of a regional scale of approach will improve the simulation of large scale urban phenomena. At this scale, cities within broader urban systems compete between them in order to attract population, employments, and public investments. The evolution of population and employment observed during large periods and the flows between cities can be used to estimate degrees of relationship between them. Considering that these relationships depend largely on neighborhood conditions and that large scale cells can be observed with a useful amount of reliable data (municipalities, cities) it is clear that a CA-based model may be used to simulate urban evolution at a regional, therefore macro-scale. At this scale, the assessment of aggregate land use demand – for housing, industrial, or tertiary land uses – through population and employment growth can be more representative of urban growth than the disaggregate amount determined for each land use, which is traditionally used by other CA models. In opposition, at a city/neighborhood scale – the local scale – land use change results from the distribution of each land use (considered in a disaggregate level). In fact, land use demand can be estimated as the amount of land necessary for each land use considering population and employment growth. Then, a set of disaggregate land uses can be assigned to different cells in order to meet land use demand. This multi-scale approach is the consideration of two levels of simulation: the regional level, in which the goals are to simulate regional evolution and to assess land use demand from population and employment evolution through time; the local level, in which the goal is to assign different land uses to

different locations (cells or parts of cells) in order to meet land uses demand considering local interaction.

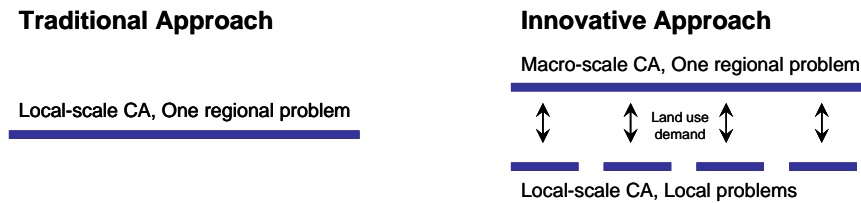


Figure 2.1 – Multi-scale CA structure

Another issue that needs careful attention regards the cell. The CA model developed was based on irregular cells, which was an innovative approach. The goal was to use what was called “natural cells”. In a multi-scale approach local scale cells should be as close to the urban structure as possible; at a regional scale, municipalities or other intermediate levels of administration can be considered as a natural option. The use of irregular cells is proposed as the basis for the simulation at regional and local scales.

Neighborhood is also a critical issue. Neighborhood is commonly (if not exclusively) considered by the strict concept inherited from the mathematical formulation of CA. This concept is based only on the consideration of a set of physical neighbors to one cell: these neighboring cells could be those which are directly connected to the cell considered or they could be the group of cells that are within a given range from that cell (which can be set by a radius or a number of cells in every direction). But this concept is far from being representative of how cities work. The concept of neighborhood must be able to reproduce how agents interact, considering both spatial and functional levels of interaction. Neighborhood must shift from the concept of a limited area to a larger and possibly disconnected part of the territory both at regional and local scales.

A multi-scale approach requires some attention on the definition of transition rules for both scales. At a regional level of analysis, it is important to notice that the goal is to simulate the macro interactions that are observed within a region. These interactions can be assessed using macro-scale indicators of population, employment, and commuting flows, for example. Transition rules and cell states will relate to this indicators and to measures of interaction. At a local scale, the goal is to simulate the distribution and growth of land use in a disaggregate manner. These phenomena depend on a series of factors related with land suitabilities, land use demand, accessibility, among many others. At this scale, transition rules will relate to measures of urban potential for each land use considering all the other land uses. The CA concept of cell state implies the consideration of a finite set of acceptable states for each cell. This concept is far from reality in urban phenomena. Homogeneity is very difficult to observe in any parcel of land of any dimension. This issue will be carefully addressed during the research.

Land suitability is also an important issue to attend. At a regional level, the analysis is made with an aggregate perspective and land suitability must be taken into account as a measure of comparison for particular issues as general environmental quality or landscape and wildlife protection policies. At a local level, the comparison between land suitabilities for every land uses is determinant for the assessment of the demand for different and/or competitive land uses. Therefore, at this level of analysis it is imperative to develop a robust set of land suitability indicators.

Accessibility is strongly linked to land use. Accessibility is also strongly dependent on the scale of analysis. In order to correctly simulate accessibility conditions and evolution through time, different transportation modes must be considered and their

scopes of influence must be attended. Air and maritime transportation modes have a regional scale of influence, as the number of network nodes located in a given region is always small. On the contrary, road and rail transportation modes have both a regional scope (regional highways and railroads systems) and a local one (city road network, subway rail systems).

Another important issue regards the calibration process. Urban growth simulation is difficult to calibrate and validate due to its complexity. There are too many variables at stake and their behaviors are extremely complex and strongly interdependent. The choice for calibration based on optimization is then fully justified. The local CA model presented earlier was calibrated with an optimization procedure based on the Particle Swarm technique. This technique has been successfully applied to problems where there is a large set of calibration parameters. However, in order to obtain the most reliable simulation results possible, it is prudent to consider other calibration procedures based on other techniques, such as Artificial Neural Networks or Fuzzy Logic analysis, combined with sensitivity analysis. Another important issue regarding model calibration relates to the use of performance measures. It is also important to develop and to test different performance measures based on physical analogies.

It is imperative to address the important issue of policy testing. It is widely accepted that policy testing is the ultimate goal of urban simulation. The use of simulation by itself is redundant because it tends to produce futile results to decision makers. Simulation must be able to incorporate the practical needs of planners and of the planning process. There are many ways for simulation to help the planning process. Simulation is oriented for understanding and reproducing real phenomena in a controlled environment, aiming to explain how these phenomena work and how can they be manipulated. However, these features do not provide planning with the necessary tools for dealing with issues that are strongly influenced by uncertainty. Therefore, simulation must be more oriented for creating flexible modeling tools which allow the configuration of a wide set of scenarios. The goal is to enhance the ability of controlling all the parameters of the problems at hand, enabling a helpful use of models by planners. One of the major goals of the research is to effectively incorporate policy testing in the simulation package to be developed. This process is based on the identification of candidate issues to be tested for every component of the model. Its implementation is an ongoing process that is expected to last even after the end of the development stage: every time a new issue is set to be tested the model must be able to change in order to meet specific simulation needs.

Finally, it is imperative to develop modeling tools that are able to break with historical trends under given conditions. Common urban transformations are usually the result of single decisions localized in time as major urban renovation operations. These types of transformations are very difficult to capture by any model. This will be a matter of intensive research. CA work with a set of transition rules that are calibrated considering the historic evolution of a problem. The model must be able to generate new transition rules after observing a trend that can not be explained by the past evolution.

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